# Equatorial and High Latitude Irregularities: Magnetic Storm Effects in Solar Maximum Years

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## LONG TERM GOALS

The effects of the ionosphere particularly at high latitudes and in the region of the magnetic equator have been to deteriorate radio wave propagation from rockets and satellites. Understanding the coupling between the auroral effects and the equatorial effects particularly during magnetic storms is the long term objective. The long term view is that if one understands the processes, then forecasting these effects can be possible. Even the forecasting during storm conditions (which last for many hours and sometimes for days) the knowledge that the deterioration is due to natural conditions rather than equipment problems will be helpful to field operations. The goal is to use many sensors to do the forecasting.

## OBJECTIVES

The grant objective was to study and understand the physics of ionospheric E and F layer irregularities in order to warn and forecast disturbances to UHF and microwave transmissions such as FLEETSATCOM and GPS. We first studied the high latitude effects in the auroral oval and emerged with an understanding of the dynamics of disturbances to GPS transmissions using data from stations such as Fairbanks, Tromso, and Reykjavik. Then we turned to the coupling between the effects of high latitudes and equatorial regions. In the equatorial anomaly region, fades of 20 dB and greater have been found during years of high sunspot number. Cities such as Santiago, Bogotá, Cairo and Singapore are in the region known as the anomaly region and are affected by F layer irregularities.

## IMPACT/APPLICATIONS

We have been concerned throughout the length of this contract with applications in the equatorial region. In worst cases F layer irregularities produce errors in distance and at times may interfere with the acquisition of satellite signals. Our aim is to see if there is a forecasting tool to tell of signal problems particularly in the anomaly region of the magnetic equator. This region is distant from the magnetic equator with effects observed from 11° to 18° from the magnetic equator. We now feel there

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14. ABSTRACT

**The effects of the ionosphere particularly at high latitudes and in the region of the magnetic equator have been to deteriorate radio wave propagation from rockets and satellites. Understanding the coupling between the auroral effects and the equatorial effects particularly during magnetic storms is the long term objective. The long term view is that if one understands the processes, then forecasting these effects can be possible. Even the forecasting during storm conditions (which last for many hours and sometimes for days) the knowledge that the deterioration is due to natural conditions rather than equipment problems will be helpful to field operations. The goal is to use many sensors to do the forecasting.**

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is the possibility of forecasting. We are exploring the use of auroral oval magnetograms to determine where and when equatorial irregularities will appear. We use both data based models and magnetograms from auroral stations to determine if forecasting of these fluctuations is possible. At the same time we seek to understand the physics involved in the apparent motion of the buildup of electron density in the equatorial anomaly.

## APPROACH

Case studies of the effects of magnetic storms as shown by auroral observations have been our approach. In the recent past more data from GPS observations has come from newly activated equatorial stations; we use new stations whose data are available on Internet. Our data on ionospheric irregularities observed with all-sky imagers as airglow depletions are now being taken in key positions to determine the zonal motion of the ionospheric plasma (Martinis et al., 2002b). The nighttime motion of the drifts of the field aligned depleted areas is usually eastward.

However, in the study of the storm of April 6-7, 2000 which has been completed (Martinis et al., 2002b), the motion was westward with velocities ranging from 90 m/s in the early evening to 20 m/s at the end of the night. GPS data and ionosonde data were also available. Images at 630 nm and 777.4 nm at El Leoncito, Argentina with its dip latitude of -18 degrees were available as well as data from our all sky imager. This unit detects depletions as dark bands. The results showed strong equatorial irregularities reaching apex altitudes higher than 2000 km.

The study of this storm along with several others such as shown in our 2001 report has led us to a hypothesis for forecasting the effects of the storms which produce strong irregularities at equatorial anomaly latitudes. We shall use the studies of Fejer (2002) to determine the applicability of his analysis of vertical drift at the magnetic equator to forecast equatorial anomaly irregularities.

## WORK COMPLETED

MAGNETIC STORM EFFECTS: EQUATORIAL REGION. After examining various data sets (GPS, DMSP, ground optical depletion records, scintillations) we are able to come to a hypothesis relative to the initiation of scintillations and GPS phase fluctuations at anomaly latitudes. At the same time the physics of the rolling out of increased electron density from the magnetic equator to anomaly latitudes during these storms remains an intriguing study in physics of the equatorial region. An illustration of total electron content development is shown in Figure 1 for the October 22-23, 1996 storm. Even at 2100 Local Time there are very high levels of TEC and that means high swings of phase fluctuations for GPS receivers in that region. In Figure 2 we show the dynamics of rate of change of TEC or phase fluctuation for the storm of April 6-7, 2000 over several stations in South America removed from the magnetic equator but at anomaly latitudes compared to that of Arequipa which is on the magnetic equator. Santiago, La Plata, and Cordova are distant from the equator; in the case of Santiago 18 degrees in magnetic latitude. We have completed studies of a range of magnetic storms during both low and high sunspot years. Our next task is take the data we have collected from individual storms ranging from those in 1993 to the present and examine them for forecasting indication. We shall do this in our next study.

DURIP IMAGING STUDY. During the past year, significant progress was made on two studies of coupled thermosphere-ionosphere processes. Both of these studies address fundamental processes in

equatorial aeronomy that play important roles in the generation and suppression of equatorial plasma irregularities - the primary focus of the grant. In Colerico and Mendillo (2002) the so-called "brightness wave" (BW) in 6300 Å emissions that arise from enhanced ionospheric recombination chemistry, driven by meridional winds from the midnight temperature maximum (MTM), was compared with state-of-the-art models. The results pointed to a significant shortfall in both empirical and first-principle models. Follow up studies using a different wind formulation and NRL's new SAMI-2 models are underway, and initial results yield a BW similar to observations. These results are being prepared for publication.

Martinis et al. (2002b) analyzed Fabry-Perot interferometer (FPU) observations of zonal winds at two low latitude sites in the same longitude sector in South America. They found that winds were larger near the geomagnetic equator in comparison to those near the crests of the Appleton Anomaly region. Modeling studies showed that ion-drag effects can produce such alterations to winds at low latitudes but that current models (empirical and theoretical) have not yet achieved success in their simulations.

A follow up study of Mendillo compares our HDI telescope technique to methods used in Europe. The first use of the DURIP/HDI system in spectral media (using our new 20 cross 20 pixel image slicer) was made in 2001, and these results are being analyzed.

## TRANSITIONS

The data sets contain a large number of variables even for a particular parameter. Magnetograms from the auroral oval show at times temporal correlation but at other times differences between stations at different longitudes. The depth of variation of storms in nT shows great differences from storm to storm. The ambient state of the ionosphere at a particular local time must be a factor in the effect of a storm on areas in the equatorial region. Therefore in order to make a transition to a goal of forecasting we shall have to deal with these and many other variables.

## RELATED PROJECTS

During the past year we initiated a major collaboration with Dr. Joseph Huba (NRL) in the use of the SAMI-2 low latitude model. This model now runs on a BU computer and various disturbance scenarios are being studied.

## PUBLICATIONS

Ionospheric effects of major magnetic storms during the International Space Weather Period of September and October 1999: GPS observations, VHF/UHF scintillations, and in situ density structures at middle and equatorial latitudes, Sunanda Basu, Santimay Basu, C. E. Valladares, H.-C. Yeh, S.-Y. Su, E. MacKenzie, P. J. Sultan, J. Aarons, F. J. Rich, P. Doherty, K. M. Groves, and T. W. Bullett, J. Geophys. Res., 106, A12, 30, 389-30, 413, 2001

The current state of investigations regarding the thermospheric midnight temperature maximum (MTM), M. Colerico, and M. Mendillo, in press J. Atmos. Solar. Terr. Phys. 2002

The intrusion of auroral processes upon the low latitude dynamics and irregularities, C. Martinis, J. Aarons, and M. Mendillo, Proceedings of Ionospheric Effects Symposium, Alexandria, VA, May 2002a

Latitude dependence of zonal plasma drifts obtained from multi-sire airglow observations, C. Martinis, V. Eccles, J. Baumgardner, J. Manzano, and M. Mendillo, in revision J. Geophys. Res., 2002b

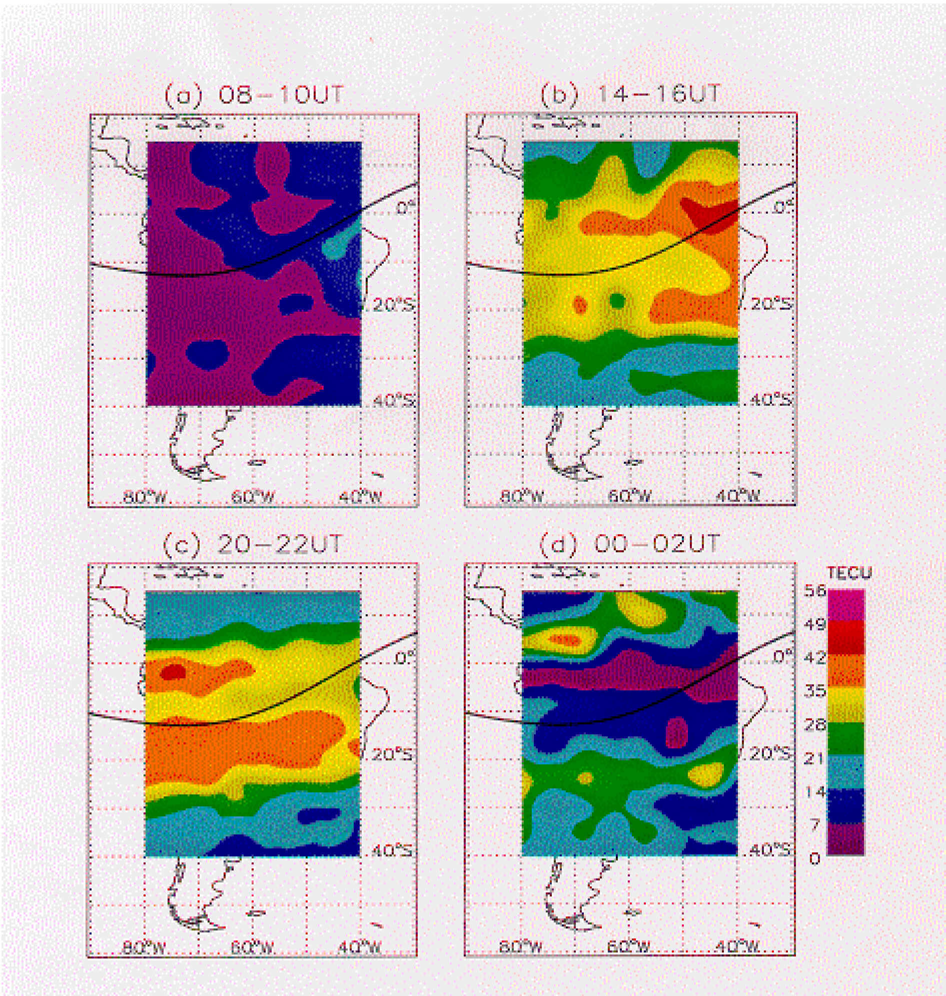


***Figure 1: Examples of "TEC snapshots" over the full continent of South America. These maps are derived from GPS observations over two-hour intervals using seven stations of on-line TEC data. The day shown is 23 October 1996, a case with a dramatic evolution of the "equatorial ionization anomaly (EIA)" throughout the day. The mean local times for the four frames shown are 0500 LT, 1100 LT, 1700 LT and 2100 LT. Data in this format can be used to characterize group delay effects on geolocation systems and for the study of ionospheric storms.***

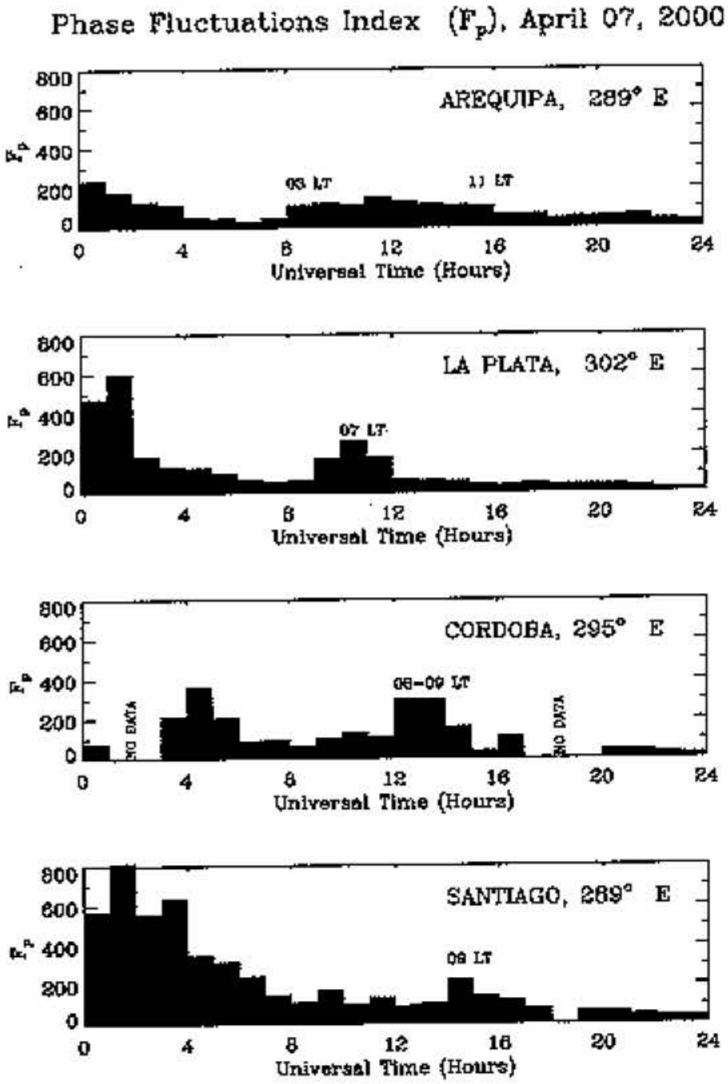


***Figure 2:  Examples of the Boston University derived "GPS phase fluctuation index (Fp)" using four stations in South America during the storm period 7 April 2000.  The Fp index is very successful in describing the local time and spatial evolution of equatorial spread-F (ESF) events.  In the case shown here, episodes of post-sunset and post-midnight ESF occur during the same storm period.  [Taken from Martinis et al. (2002a).]  Such longitude specific responses are an area of prime focus in the proposed study, one that will use the plasma drift model vs. stormtime.***